Laboratory X-ray Studies for Unraveling High-Resolution Celestial Spectra

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Abstract

The diagnostic utility of the high resolution instruments flown on Chandra, XMM-Newton, and Suzaku is directly coupled to, and often limited by, our understanding of the atomic physics governing the X-ray emission. Hence, high accuracy, systematic laboratory measurements of X-ray emission from highly charged ions provide the necessary basis for interpreting spectra measured by X-ray observatories. Over the past two decades, electron beam ion traps have been used in laboratory astrophysics experiments to study X-ray emission from highly charged ions. These data provide reliable benchmarks of theoretical calculations and have addressed specific problems facing the X-ray astrophysics community, and will prove invaluable when interpreting the spectra measured using the SXS on Astro-H. Results focussed on addressing the Fe XVII problem and measuring the rest wavelengths of Kα transitions in L-shell ions of silicon are summarized.

Key words: Suzaku-Maxi 2014: proceedings — X-ray — laboratory astrophysics — Suzaku

1. The Fe XVII problem

Neon-like Fe XVII is one of the most studied highly charged ions. X-ray emission from Fe XVII, which falls in the $\sim$ 10–18 Å wavelength band, has been observed in a variety of X-ray sources, including the corona of the Sun, other stellar coronae, clusters of galaxies, and X-ray binaries. Although Fe XVII has a strong spectral signature consisting of several distinct X-ray lines, a model of the spectrum has not been produced at the level of accuracy necessary to consistently model the high resolution spectra provided by modern X-ray observatories. To address this problem, many experimental and theoretical studies have been completed (Brown et al. 1998, Beiersdorfer et al. 2002, Gu 2003, Loch et al. 2006, Chen et al. 2008), specifically, this line emission was a main focus of the laboratory astrophysics program. Early on, calculations of the relative electron impact excitation cross sections of the 3d to 2p resonance and intercombination lines, located at 15.01 and 15.26 Å, respectively, were found to disagree with experiment (Brown et al. 1998). More detailed measurements of the absolute cross sections showed that the problems lie predominately with the strong resonance line (Brown et al. 2006). A variety of explanations have been put forth to explain the discrepancies (Brown & Beiersdorfer 2012), most related to the physics of the collision between the impact electron and the ion. Gu (2009) suggested that the problems, however, may lie in the calculation of the atomic structure. To determine if the problems with the models lie in the atomic structure or collisions, we used the FLASH-EBIT electron beam ion trap coupled to the Linac Coherent Light Source Free Electron X-ray Laser (LCLS-FEL) to measure the relative oscillator strength of the resonance and intercombination lines in Fe XVII (Bernitt et al. 2012). We found (see figure 1) that no atomic model can reproduce the results, and that the discrepancies between theoretical and experimental excitation cross sections are most likely rooted in the theoretical treatment of the atomic structure.

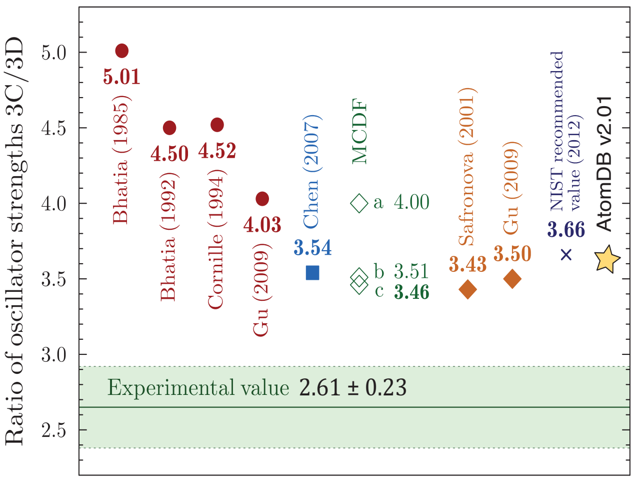

Fig. 1. Theoretical values in red are used in typical scattering calculaltions. Squares and diamonds are results from calculations where the wavefunctions were optimized for mixing among electronic levels. The more mixing that is allowed, the closer the theoretical ratio is to the experiment. The AtomDB relative oscillator strength has to be reduced by ~36% to agree wtih experiment. Figure and references from Bernitt et al. 2012.

2. Calibrating X-ray velocimeters using LLNL's EBIT-I

X-ray features created by K-shell absorption in L-shell ions of silicon have been detected in the Chandra spectra of Cygnus X-1. The features have been measured during the so-called dipping phase of the orbital period, i.e., the phase when clumps of material of various densities and temperatures move in the line of sight between the X-ray observatory and the accreting black hole. By measuring the Doppler shift of the absorption features and properly identifying the features with their source ion, the velocity and ionization structure of the clumps can be determined. Because of relatively large uncertainties in the theoretical rest energies, however, it has not been possible to determine the proper velocity structure. To provide accurate rest wavelengths, we have used the EBIT Calorimeter Spectrometer (ECS)(Porter et al. 2009) designed and built at the NASA/Goddard Space Flight Center, and LLNL's EBIT to measure the rest energies of the Kα features produced by Si VIII–XIII (Hell et al. 2013). Figure 2 shows a comparison between the laboratory-measured spectrum and the spectra measured during different dipping stages of Cygnus X-1 at

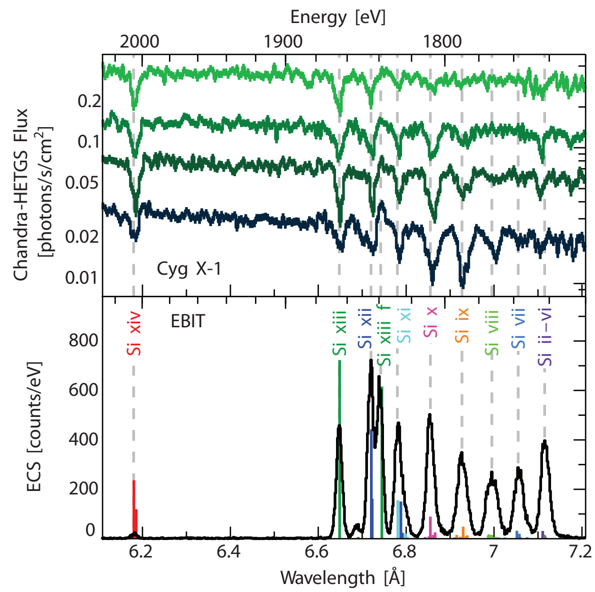

Fig. 2. Comparison of measurements to absorption spectra of highly charged Si ions measured by Chandra for Cygnus X1 during different dipping stages at superior conjunction, i.e., at phase $\phi \approx 0$. The laboratory spectra were measured using the NASA/GSFC ECS coupled to LLNL's EBIT-I electron beam ion trap (Hell et al. 2013).

superior conjunction, i.e., at phase $\phi \approx 0$. The velocity structure determined by the Doppler shifts based on the laboratory-measured rest wavelengths show that all the ionization states have the same velocity, supporting the idea of an onion-like ion structure for the clumps (Hell et al. 2013).

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